Section 941

MARSHALL METHOD OF MIX DESIGN FOR LARGE AGGREGATE

941.01 Scope

This method of test covers a procedure for the design of hot bituminous paving mixtures containing asphalt or tar and aggregate up to 2 inch maximum size by means of the Marshall apparatus. A recommended asphalt content for the aggregate and asphalt used is determined by performing a density-air voids and stability-flow analysis on cylindrical specimens batched, mixed, and compacted in the laboratory.

941.02 Apparatus

A detailed description of most of the following apparatus may be found in AASHTO T-245 or ASTM D-1559:

1. Specimen Mold Assembly - Cylindrical molds having an inside diameter of 6 inches and 4.5 inches in height.

2. Compaction Hammer - Either a hand operated or mechanically operated hammer may be used. Hand or mechanically operated hammers without rotating bases shall have a flat circular tamping face. Hammers with rotating bases shall have a beveled circular tamping face. Hammers shall have a tamping face 5-7/8 inches in diameter and a 22.5 lb sliding weight with a free fall of 18 inches.

3. Compaction Pedestal - The compaction pedestal shall consist of a 8 x 8 x 18 inch wooden post capped with a 12 x 12 x 1 inch steel plate. Some modification to these dimensions is necessary when a double compaction hammer is used; however, the compactive effort shall be checked to insure correlation with the standard pedestal. Also, on some mechanical compactors, the steel cap is a part of the compactor. The wooden post shall be oak, pine or other wood having an average dry weight of 42-48 lbs/ft^3. The wooden post shall be secured by angle brackets to a solid concrete slab. The steel plate shall be firmly fastened to the post. The pedestal assembly shall be installed so that the post is plumb and the plate is level.

4. Specimen Mold Hammer - The holder shall be mounted on the compaction pedestal or mechanical compactor so as to center the compaction mold over the center of the post. It shall hold the compaction mold, collar, and base plate securely in position during the compaction of the specimens.

5. Breaking Head - The breaking head shall have an inside radius of curvature of 3 inches.

6. Loading Jack - A screw jack mounted in a testing frame. The jack shall produce a uniform vertical movement of 2 inches per minute. An electric motor may be attached to the jacking mechanism. In lieu of the loading jack, a mechanical or hydraulic testing machine may be used provided the rate of movement can be maintained at 2 inches per

minute while the load is applied.

7. Proving Ring Assembly - A proving ring of 10,000 lb capacity and a sensitivity of10 lb up to 1000 lb and 25 lb between 1000 and 5000 lb. The proving ring shall be equipped with a micrometer dial graduated in 0.0001 inch. Upper and lower proving ring attachments are required for fastening the proving ring to the testing frame and transmitting the load to the breaking head. In lieu of the proving ring assembly, any suitable load-measuring device may be used, provided the capacity and sensitivity meet the above requirements.

8. Flow Meter - A flow meter consisting of a guide sleeve and a gauge. The activating pin of the gauge shall slide inside the guide sleeve with a slight amount of frictional resistance. The guide sleeve shall slide freely over the guide rod of the breaking head. The flow meter gauge shall be adjusted to zero when placed in position on the breaking head when each individual test specimen is inserted between the breaking head segments. Graduations of the flow meter gauge shall be in 0.01 inch divisions. In lieu of the flow meter, a micrometer dial or stress-strain recorder graduated in 0.001 inch may be used to measure flow.

9. Ovens or Hot Plates - Ovens or hot plates for heating aggregates, bituminous material, specimen molds, compaction hammers, and other equipment to the required mixing and molding temperatures. It is recommended that the heating units be thermostatically controlled so as to maintain the required temperature within 36.5 EF. Suitable shields, baffle plates, or sand baths shall be used on the surfaces of the hot plates to minimize localized overheating.

10. Mixing Apparatus - Any type of mechanical mixer may be used, provided the mix can be maintained at the required mixing temperature, and will produce a well coated, homogenous mixture of the required amount in the allowable time, and further provided that essentially all of the batch can be recovered. A metal pan or bowl of sufficient capacity and hand mixing may also be used.

11. Water Bath - A water bath at least 6 inches deep and thermostatically controlled so as to maintain the bath at 140 ± 34 EF. The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 2 inches above the bottom of the bath.

12. Miscellaneous Equipment:

    (a) Containers for heating aggregates such as flat-bottom metal pans.

    (b) Containers for heating bitumen such as gill-type tins, beakers, pouring pots, or sauce pans. A thermostatically controlled asphalt pot is recommended.

    (c) Mixing tools for spading and hand-mixing.

    (d) Thermometers for determining temperatures of aggregates, bitumen, and the bituminous mixtures. A range of 98 to 401 EF with a sensitivity of 2 EF is required.

(e) Thermometers for the water bath with a range of 68 to 158 EF and sensitive to 0.5 EF.

(f) A balance with a capacity of 2000 g and sensitive to 0.1 g capable of weighing suspended specimens.

(g) A balance with a capacity of at least 5000 g and sensitive to 1 g for batching mixtures.

(h) Gloves for handling hot equipment.

(i) Rubber gloves for removing specimens from the water bath.

(j) Marking crayons for identifying specimens.

(k) A flat-bottomed scoop for batching aggregates.

(l) Large spoon or sugar scoop for placing bituminous mixtures in specimen molds.

(m) Filter papers for molds.

941.03 Aggregate Preparation and Batching

Perform a sieve analysis on all aggregate intended for use in the design according to AASHTO T-27: Sieve Analysis of Fine and Coarse Aggregates. Determine from the sieve analysis how aggregates are to be blended to produce the desired design gradation. For preliminary work the design gradation shall be within the applicable specification band. For construction job mix design, the design gradation shall be specified by the contractor.

The method of analyzing aggregate gradations and combining of aggregates to obtain the desired design gradation are numerous. For example, scalping, wasting, crushing, washing, sieving, etc., may be required. In general, aggregates are combined to approximate the design gradation and then separated into the desired size fractions by dry sieving, normally down to the No. 4 sieve. Individual samples are then batched to the design gradation using individual sizes down to the No. 4 sieve and using the minus No. 4 material as is. Batch three individual samples for each increment of asphalt anticipated in the design. The aggregate batch weight shall be such that the compacted specimen will be approximately 3-3/4 inches in height (about 4000 g). Normally, twelve samples are sufficient. Batch two individual samples for maximum specific gravity (Rices) to the weight specified in AASHTO T-209: Maximum Specific Gravity of Bituminous Paving Mixtures. It is also recommended that a gradation sample be batched and tested prior to running the design to verify samples were batched properly.

941.03.1 Bituminous Binder

As Job Requires.

941.04 Mixing and Compaction Temperatures

1. Asphalt Cement - The temperature of the asphalt cement when incorporated into the mix shall be that temperature required to produce a viscosity between 0.0016 and 0.0032 ft^2/s.

2. Aggregate - The temperature of the aggregate when incorporated into the mix shall be approximately 82 EF above the asphalt cement temperature specified in 941.04(1).

3. Mixing Temperature - The temperature of the mix, during mixing, shall be the same as the asphalt cement temperature specified in 941.04(1).

4. Compaction Temperature - The temperature of the mix at time of compaction shall be that temperature required to produce an asphalt cement viscosity between 0.0027 and 0.0032 ft^2/s.

941.05 Batching and Compacting Test Specimens

In order to determine the recommended asphalt content, a series of test specimens are batched and compacted for a range of different asphalt contents. The range of asphalt content shall be in one-half percent increments with three specimens for each increment. The range should be such that it will be possible to determine the optimum asphalt content. An optimum asphalt content must first be estimated and a set of three specimens compacted at this asphalt content. Judging by the richness of the mix, a decision can then be made as to the range in asphalt content to be used. For most aggregates, a good starting point is 3.5 percent asphalt cement.

Prior to batching and compacting the specimens, heat the asphalt and aggregate to the temperatures specified in 941.04 and bring mold assembly, hammer face, and mixing bowl to a temperature between 93 and 149 EF. During heating of the asphalt, the container shall not come in direct contact with a flame or unshielded hot plate and should be constantly stirred. To eliminate this problem, a thermostatically controlled asphalt pot is recommended.

The specimens shall be batched and compacted as follows:

1. Place the preheated mixing bowl on the balance and tare to zero.

2. Place the heated aggregate in the mixing bowl, thoroughly dry mix and weigh. Form a crater in the aggregate to prevent asphalt cement from coming in contact with the mixing bowl.

3. Expressing the asphalt content (AC) as a percent of the total weight of the mix, calculate the total batch weight as follows:

$$100\left(\frac{Weight\ of\ Agg.(Oven\ Dried)}{100\ \&\ \%\ AC}\right)\ '\ Total\ Batch\ Weight$$

4. Add the heated asphalt to the aggregate, pouring into the preformed crater until the calculated total batch weight is achieved. At this point, the temperature of the aggregate and asphalt shall be within the limits specified in 941.04.

5. Commence wet mixing and continue mixing until the aggregate is thoroughly coated with asphalt. Work rapidly to insure the temperature of the mix does not fall below the mixing temperature specified in 941.04.

6. Place a filter paper in the bottom of the preheated mold. Place the entire batch in the mold being sure the mixing bowl is thoroughly scraped clean. The Large Aggregate or Stones are placed in the center with finer mix around the sides. Spade the mixture vigorously with a spatula or trowel 15 times around the perimeter and 10 times over the interior. Smooth the surface of the mix to a slightly rounded shape and check the temperature. The temperature of the mix immediately prior to compaction shall be within the limits of the compaction temperature specified in 941.04. Place a filter paper on top of the mix.

7. Place the mold assembly on the compaction pedestal in the mold holder. Unless otherwise specified, apply 112 blows to the specimen with the compaction hammer (free fall of 18 inches). Apply 75 blows for facilities that will be used by aircraft with tire pressures greater than 100 psi. Be sure the axis of the compaction hammer is perpendicular to the base of the mold assembly during compaction. Remove the base plate and collar, turn the mold over and reassemble. Apply the same number of blows to the reversed specimen. Remove the filter paper after compaction is complete and while the specimen is still hot to prevent sticking. Batch and compact the remaining specimens according to 941.05(1) through 941.05(7).

8. Allow all specimens to cool sufficiently before removal from mold to insure against damage. Cooling may be accomplished by means of table fans, running water, etc. If water is used, precautions shall be taken to insure that the water does not come in contact with the specimen. Remove the specimens from the mold, place on a smooth, flat surface, and cool to room temperature.

9. Batch and mix the maximum specific gravity samples (Rices) according to 941.05(1) through 941.05(5) at the estimated optimum asphalt content. Test in accordance with AASHTO T-209: Maximum Specific Gravity of Bituminous Mixtures.

941.06 Bulk Specific Gravity of Compacted Specimens

Determine the bulk specific gravity of the compacted specimens in accordance with AASHTO T-166: Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.

941.07 Stability and Flow Determination

Each specimen shall be tested for stability and flow as follows:

1. Measure the height of the specimen to the nearest 1/16 inches Then immerse the specimen for 30-40 minutes in a water bath maintained at a temperature of 140 ± 34 EF for asphalt specimens or 100 ± 34 EF for tar specimens. As an alternative, the specimen may be brought to the desired temperature by placing in an oven, maintained at the same

temperature, for a minimum of 2 hours.

2. Thoroughly clean the guide rods and the inside surface of the test heads prior to use and lubricate the guide rods so that the upper test head slides freely over them. The testing head temperature shall be maintained between 70 and 100 EF, using a water bath when required.

3. Remove the specimen from the water bath and place it in the lower segment of the breaking head. Place the upper segment of the breaking head on the specimen and place the complete assembly in position on the testing machine.

4. Place the flow meter in position over one of the guide rods and adjust the flow meter to zero while holding the sleeve firmly against the upper segment of the breaking head while the test load is being applied.

5. Apply the load to the specimen by means of the constant rate of movement of the testing machine head (or load jack) of 2 inches per minute. Continue this load application until the maximum load is reached and the load decreases as indicated by the dial. Record the maximum dial reading noted. Release the flow meter sleeve or note the flow meter reading the instant the load begins to decrease. Record the dial reading for stability and flow. The elapsed time for the test from the removal of the test specimen from the water bath to the maximum load determination shall not exceed 30 seconds. The stability in pounds shall be obtained by means of the conversion charts provided with each testing machine.

6. The stability in newtons for specimens whose height differ from the standard 3-3/4 inches shall be corrected by multiplying the measured stability by the proper correction factor. The correction factor may be determined from the height or volume of the specimen according to the following table. Record the correction factor and the corrected stability.

Table 1: Stability Correlations Rations[A]

Specimen Thickness[8] inches (approx.)	Specimen Volume in^3	Correlation Ratio
3.50	98.1 to 99.2	1.12
3.56	99.9 to 101.6	1.09
3.62	101.7 to 103.3	1.06
3.68	103.4 to 105.1	1.03
3.75	105.2 to 106.9	1.00
3.81	107 to 108.6	0.97
3.87	108.7 to 110.4	0.95
3.93	110.5 to 112.2	0.92
4.00	112.3 to 114	0.90

[A]the measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 3.75 inches thick specimen.

[8]Volume - thickness relationship is based on a specimen diameter of 6 inches.

941.08 Calculations

Having completed the bulk specific gravity and maximum specific gravity determinations according to AASHTO T-166 and T-209, respectively, calculations for density and voids can now be performed. Values of specific gravity are to be reported to four significant figures.

(1) Bulk Density:

$$G = G_{sb}(62.4\ lb/ft^3)$$

Where:

G = The average bulk density in pounds per cubic foot.
G_{sb} = The average bulk specific gravity of all specimens having the same asphalt content.

$$G_A = \frac{100 - \%\ AC}{(\frac{100}{G_{MM}}) - (\frac{\%\ AC}{G_{AC}})}$$

(2) Combined Effective Specific Gravity of Aggregate:
Where:

G_A = Combined specific gravity of aggregate.
G_{MM} = Measured Maximum specific gravity (Rices).
G_{AC} = Specific gravity of asphalt cement.
%AC =Percent asphalt cement at which maximum specific gravity was performed, reported in hundredths.

(3)Theoretical Maximum Specific Gravity:

$$G_{TM} = \frac{100}{(\frac{100 - \%\ AC}{G_A}) + (\frac{\%\ AC}{G_{AC}})}$$

Where:

G_{TM} = Theoretical maximum specific gravity of mix for asphalt contents other than that at which the measured maximum specific gravity was performed.

G_A = Combined specific gravity of aggregate.

G_{AC} = Specific gravity of asphalt cement.

%AC = The percent asphalt cement to which the theoretical maximum specific gravity is desired, reported in hundredths.

(4) Total Air Voids:

$$V_a = \frac{(G_{mm} - G_{mb})}{(G_{mm})} 100$$

Where:

V_a = Percent total air voids by volume in mix, reported to tenths.
G_{mm} = Measured or theoretical maximum specific gravity.
G_{mb} = The average bulk specific gravity of mix.

(5) Voids in Mineral Aggregate:

$$VMA = V_a + \frac{(G_{mb})(P_b)}{(G_b)}$$

Where:

V_{MA} = Percent air voids in the mineral aggregate reported to tenths.
V_a = Percent total air voids in mix, in tenths.
G_{mb} = The average bulk specific gravity of mix.
P_b = Percent asphalt cement in hundredths.
G_b = Specific gravity of asphalt cement.

(6) Voids in Mineral Aggregate Filled:

$$VFA = \left(\frac{VMA - V_a}{VMA} \right) 100$$

Where:

VFA = Percent voids filled in the mineral aggregate, reported to tenths.

VMA = Percent air voids in the mineral aggregate in tenths.

V_a = Percent total air voids in mix, in tenths.

941.09 Evaluation of Mix Design

After the specimens have been tested and all calculations have been performed the following

graphs shall be prepared:

1. Unit weight versus asphalt content.

2. Percent air voids versus asphalt content.

3. Percent aggregate voids filled versus asphalt content.

4. Stability versus asphalt content.

5. Flow versus asphalt content.

The test values obtained for all specimens having the same asphalt content shall be averaged and these average values shall be plotted on the corresponding graphs. The separate graphs shall be analyzed and the percentages of asphalt that satisfy specifications shall be recorded.

The recorded percentages shall be averaged and the resulting average percent asphalt content shall be checked against each graph to ascertain that it still meets specifications. If this average percent asphalt is within specifications, it shall be rounded off to the nearest 0.1 percent and it then shall become the recommended optimum asphalt content.